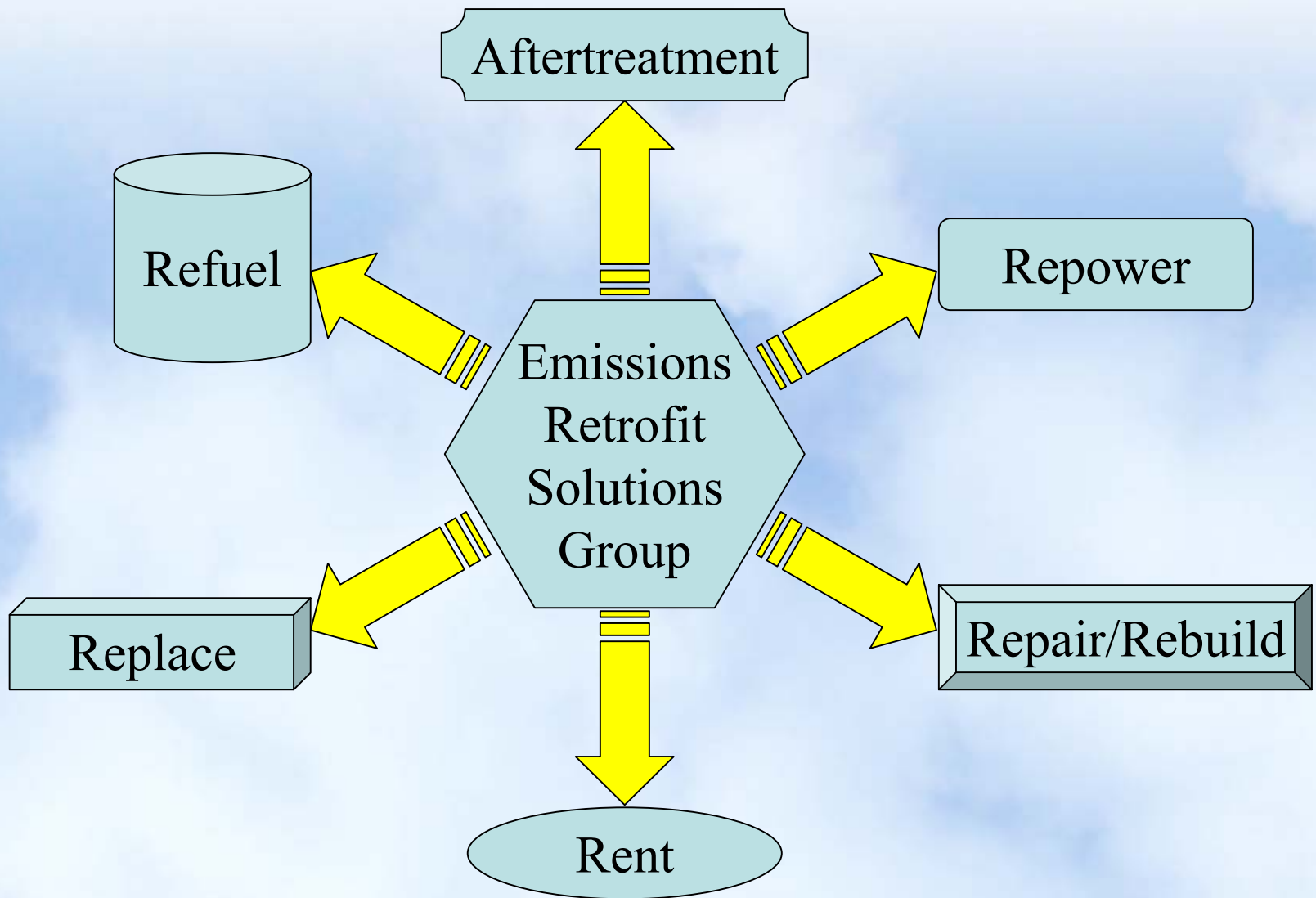


Agenda

Emissions Retrofit Solutions

- Aftertreatment
- Fuels
- Repower

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Emissions Retrofit

The adaptation of emissions reduction technologies to existing products.

C O U N T O N C A T

CATERPILLAR®

- International company based in the U.S.
 - One of the largest exporters of U.S. goods
 - 49 manufacturing plants in the U. S.
 - 59 outside of U.S.
- World's largest maker of earth moving machinery



C O U N T O N C A T



- Worldwide Dealer Organization

- 1,700 locations
- 99,348 employees
- \$8.6 billion net worth

- North America

- 500 Cat Dealer locations
- 34,000 employees
- 2,500 Truck Dealer locations

C O U N T O N C A T

Caterpillar Engine Business

- 1/3 of total revenue
- World's broadest engine line
 - 5 to 21,000 hp
- Projected to grow significantly



C O U N T O N C A T



Research & Development Commitment



\$4 Million in R & D Spent Daily!

C O U N T O N C A T



What are diesel engine emissions?

- Diesel engine emissions are the solid, liquid, and gaseous remains from combustion of diesel fuel and atmospheric air.

Regulated Diesel Emissions

Particulate Matter (PM)

Carbon from incomplete combustion

Soluble organic fractions from the fuel & lubricating oil

Sulfates formed from the sulfur in the fuel

Nitrogen oxides (NO_x)

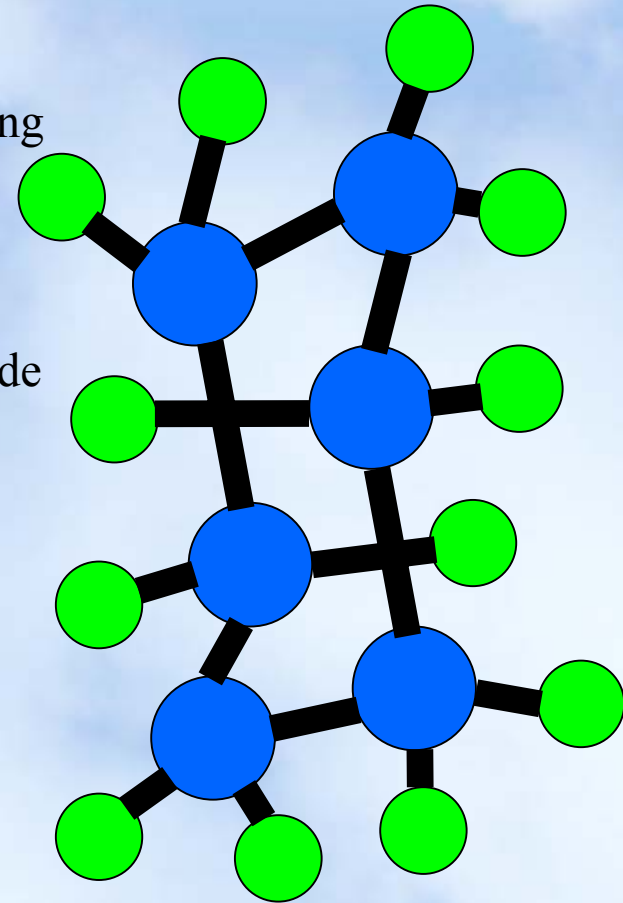
Composed of nitric oxide (NO) and nitrogen dioxide (NO_2)

Hydrocarbons (HC)

Regulated either as total hydrocarbon emissions (THC) or as non-methane hydrocarbons (NMHC)

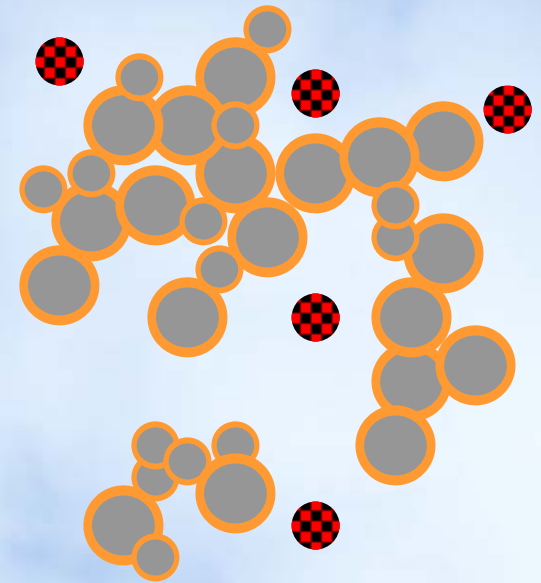
Carbon Monoxide (CO)

Smoke/Opacity



Composition of Diesel Particulate

- **Solids (SOL)**
 - ↗ Elemental carbon & ash
- **Soluble Organic Fraction (SOF)**
 - ↗ Unburned fuel and lubricating oil
 - ↗ Level varies with engine & test condition
- **Sulfates (SO₄)**
 - ↗ Hydrated sulfuric acid
 - ↗ $\text{SO}_3 + \text{H}_2\text{O} = \text{H}_2\text{SO}_4$
 - ↗ Dependent on fuel sulfur



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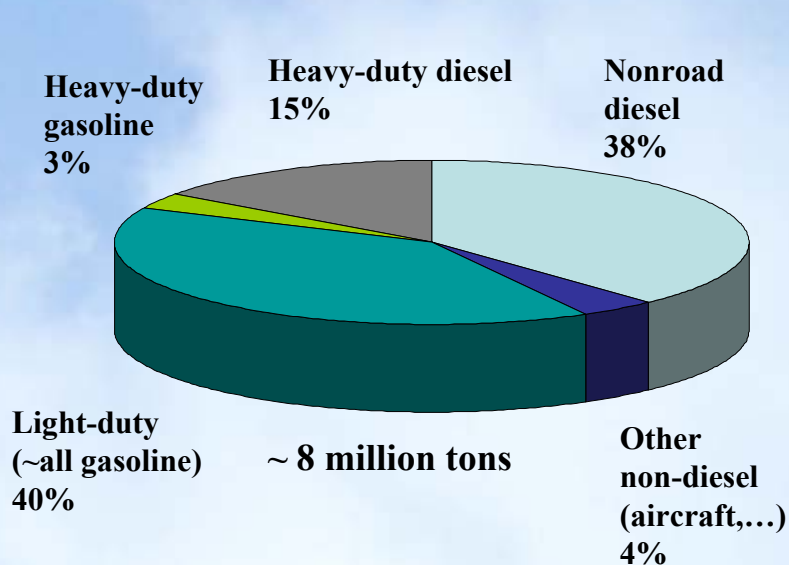
Total Particulate Matter (TPM) = SOL + SOF + SO₄

Sulfur in US Diesel Fuels

- **On-road diesel fuel**
 - 500 ppm (0.05%) max Sulfur currently
 - 15 ppm max mandated by 2006
 - more expensive

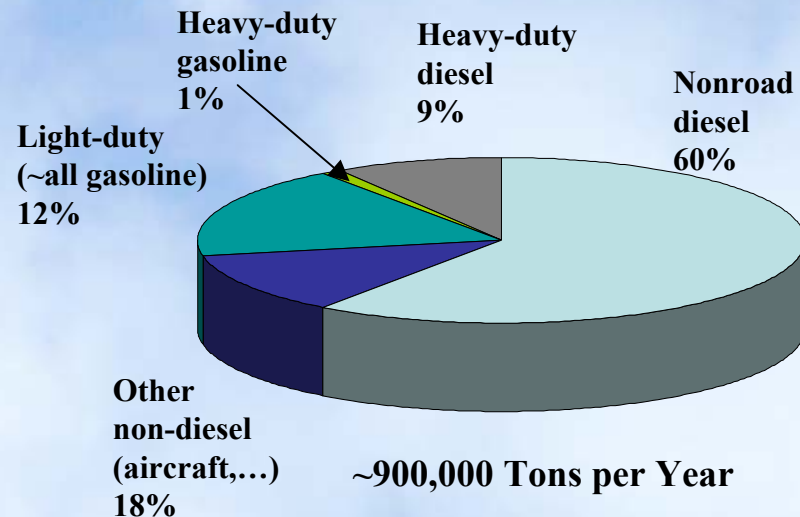
- **Off-road diesel fuel**
 - 5000 ppm (0.5%) max Sulfur
 - 500 ppm max by 2006

EPA Estimate of Mobile Source Emissions



NO_x

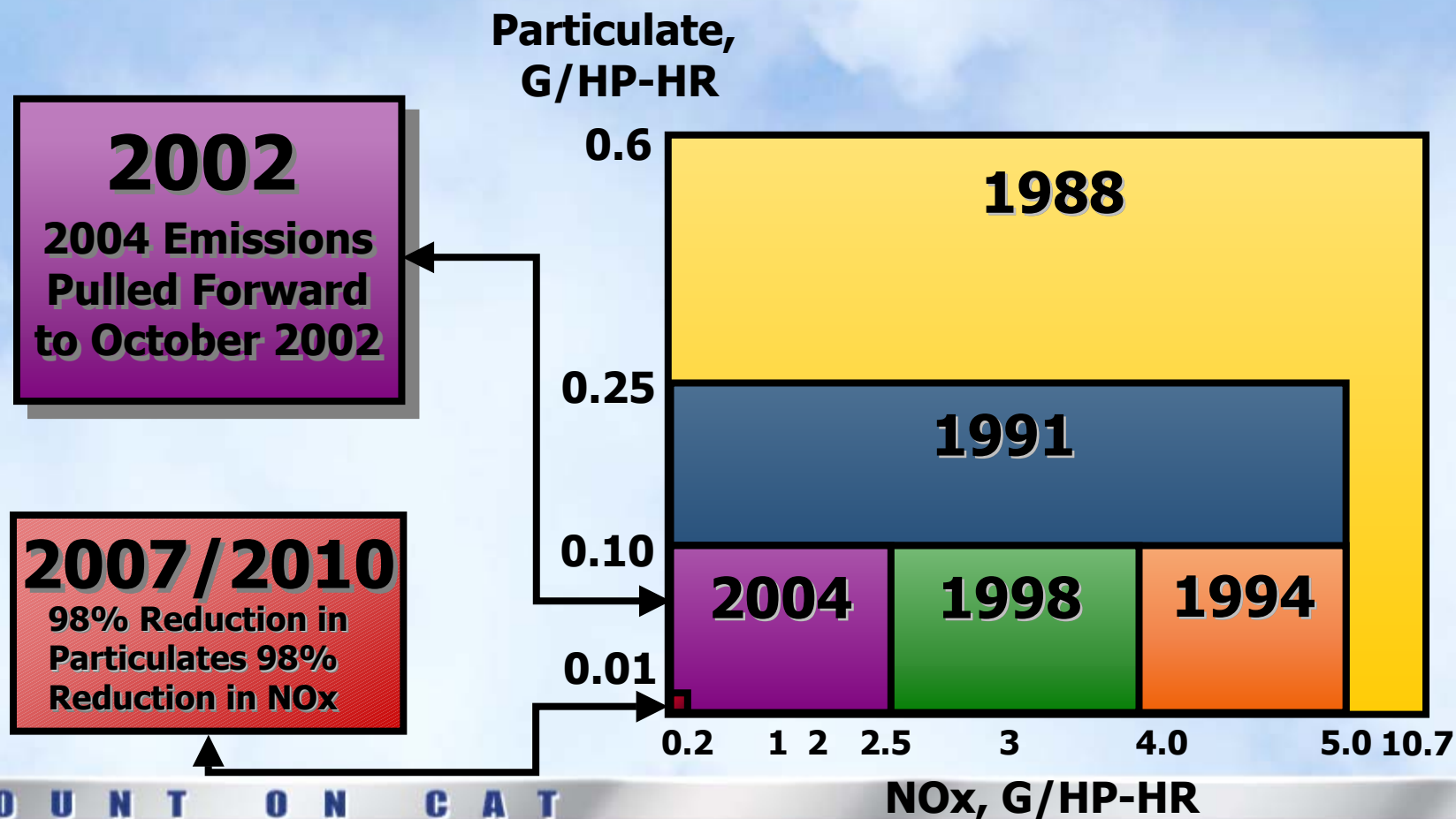
- 2010 Inventory



PM

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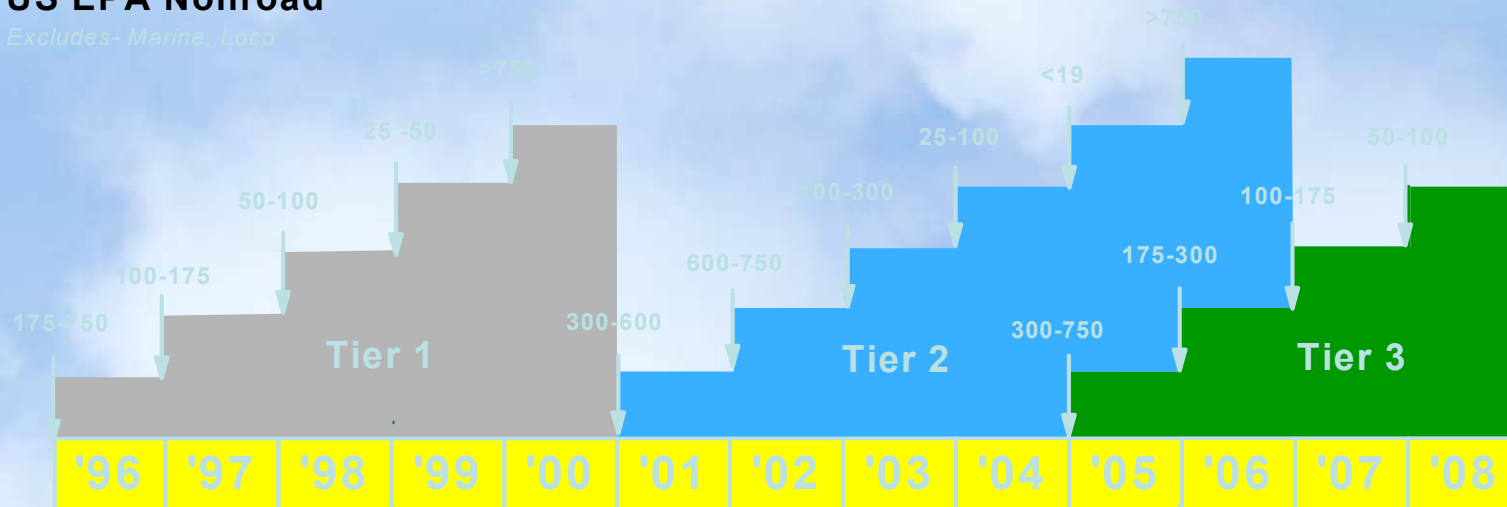
On-Highway EPA Emissions Regulations



EPA and EU Nonroad Emissions Regulations

US EPA Nonroad

Excludes: Marine, Loco



Stage I

Stage II

IMO NOx Regulation

3 dB Reduction in Machine Noise Level Required

European Nonroad

Excludes: EPG, Marine, Loco, Ag, Forest Tractors

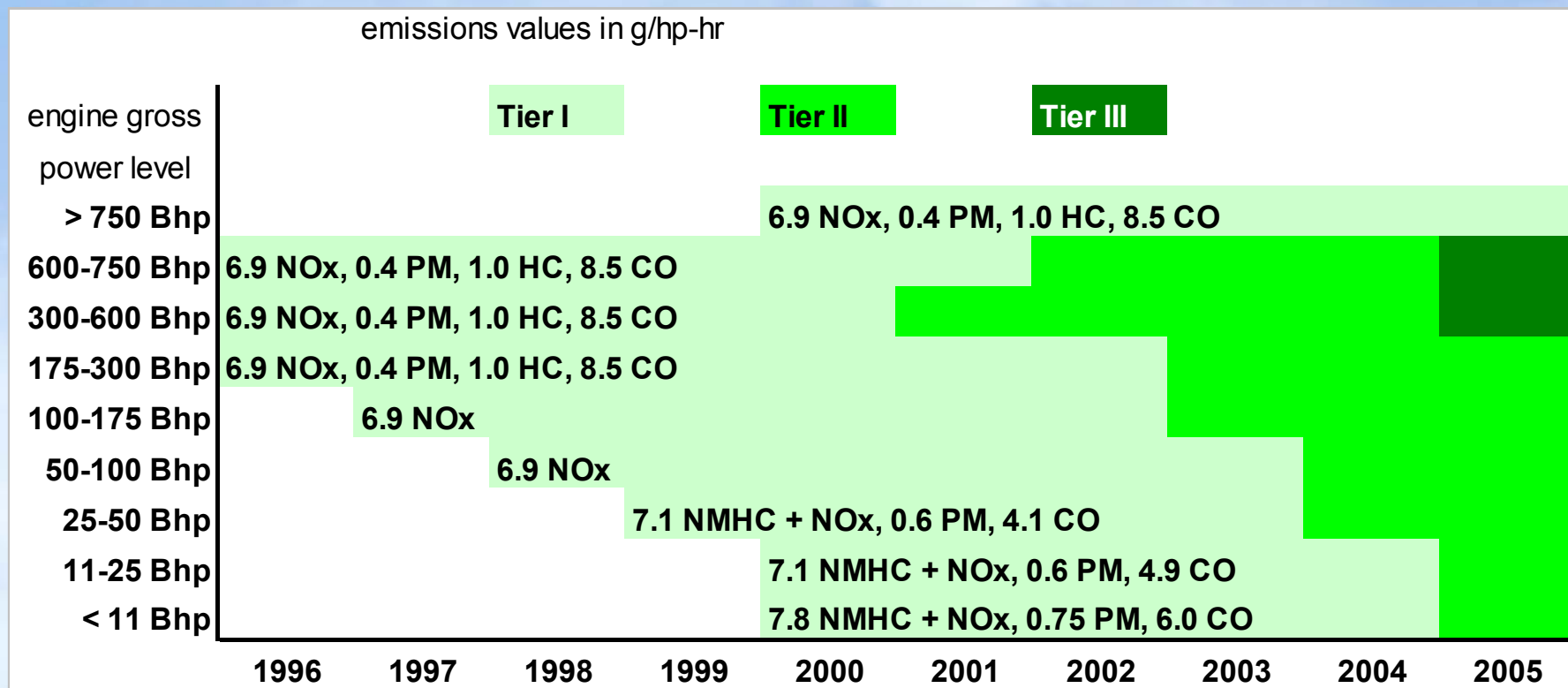
KEY:

BlackBold = Bhp

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US EPA Emissions Regulations

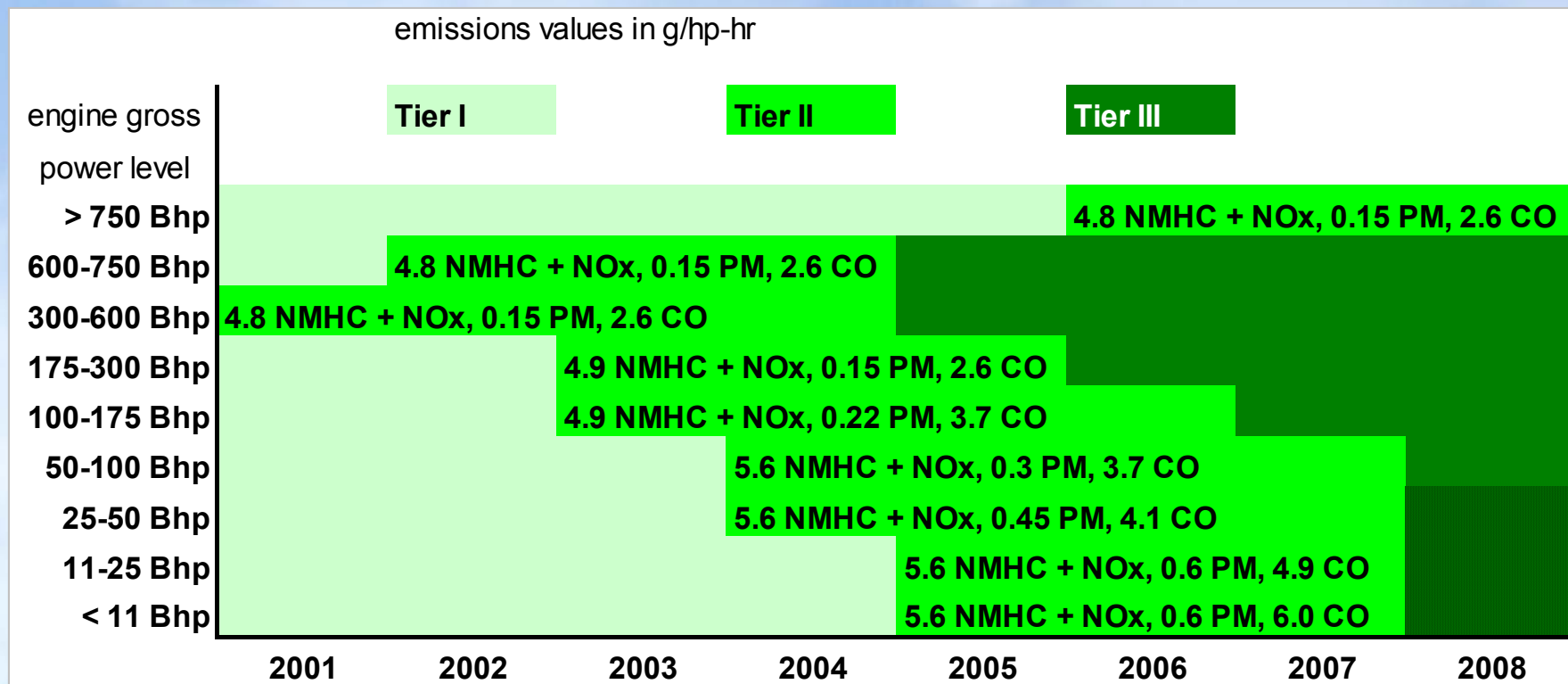
Tier 1



US EPA Emissions Regulations

Tier 2

•EPA Tier II Emissions required by January 1, 2001 for 300- 600 Bhp



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EPA Tier II “Flexibility”

- **EPA allowed for a Transition Program for Engine Manufacturers, that has become known as “Flexibility”**

“EPA desires to avoid unnecessary hardship for equipment manufacturers who install diesel engines in their products.”

“even timely information on the new engine designs may not be sufficient because of the sheer volume of redesign work needed to change diverse product offerings with limited engineering staffs.”

“In response to these concerns, the Agency is including in this final rule an OEM transition program to provide equipment manufacturers with some control of the transition process to new standards.”

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Feasibility and Economics

- Some existing diesel engines can be retro-fitted with a Catalytic Converter, Particulate Filter or SCR after treatment
- No internal modifications to the engine would be required but the exhaust back pressure is limited
- No fuel consumption penalty but Reagent cost must be considered
- NO_x levels can be reduced by 70-90%

Emissions Technology Solutions

Exhaust Gas Aftertreatment

- Diesel Oxidation Catalyst (DOC)
- Diesel Particulate Filter (DPF)
- Selective Catalytic Reduction (SCR)

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Definition of a Catalyst

- A substance that aids or speeds up a chemical reaction while remaining unchanged itself

C O U N T O N C A T

Diesel Oxidation Catalyst (DOC)



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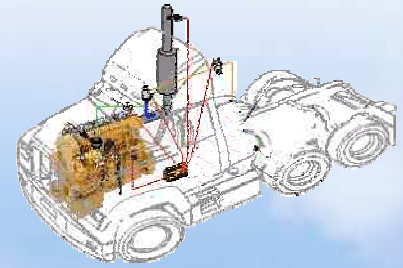
Diesel Oxidation Catalyst



- Emissions targeted
 - Hydrocarbons (HC)
 - Carbon Monoxide (CO)
 - Soluble Organic Compounds (SOF)
- Proven technology & economical
- Usually replace existing muffler
- Not fuel dependent

C O U N T O N C A T

Diesel Oxidation Catalyst (DOC)



- Stainless steel construction - for long life
- Low "skin temperature" same as conventional muffler
- No service required
 - Passive system / No "cleaning" required
- Reliability
 - Over 120,000 in service today
- OEM determines configuration
 - Single / duals/ vertical / horizontal

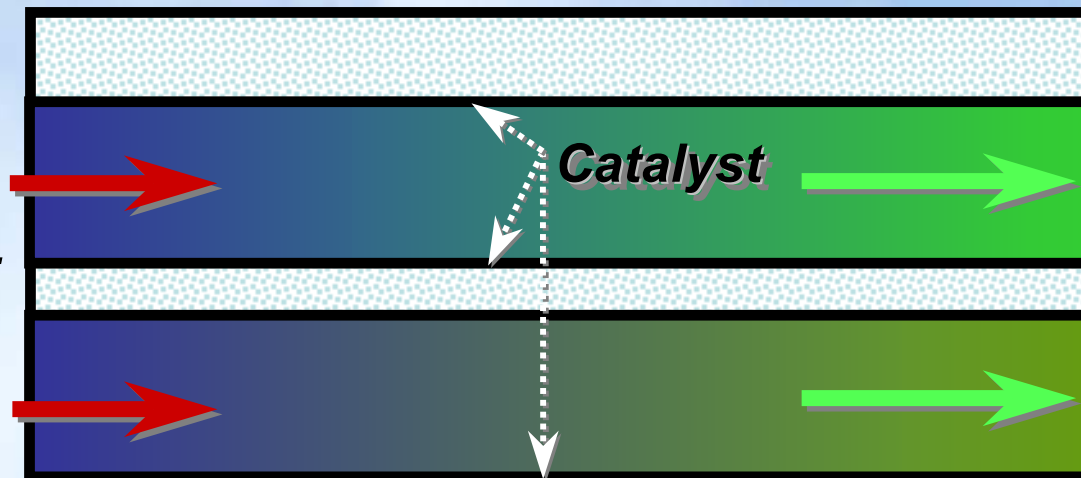


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Efficient Aftertreatment



*Exhaust
In*



Working Principle

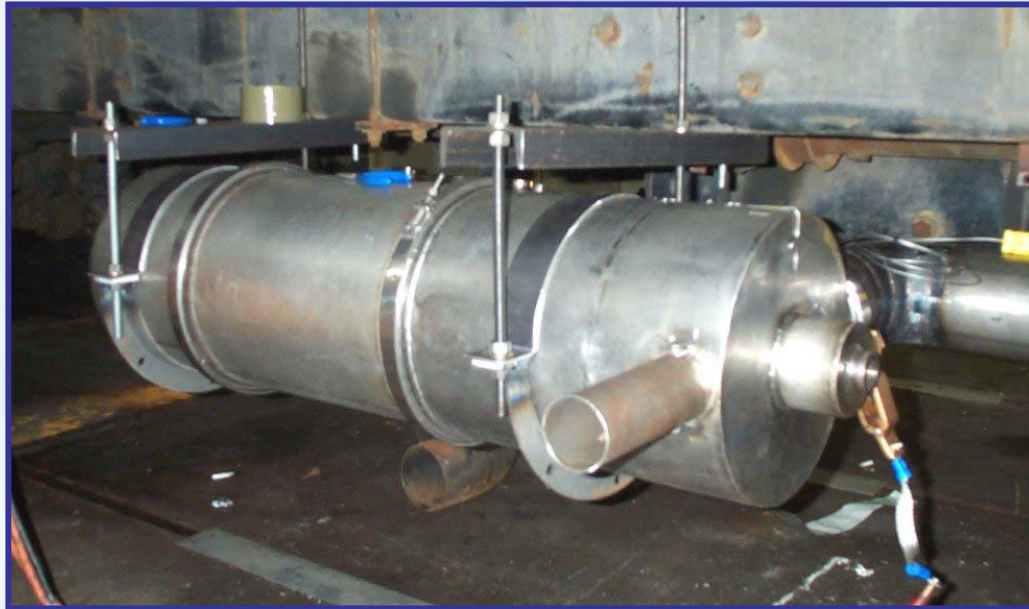
CO (Carbon Monoxide) + O₂ (Oxygen) → CO₂ (Carbon Dioxide)

HC (Total Hydrocarbon) + O₂ (Oxygen) → CO₂ (Carbon Dioxide) + H₂O (Water)

SOF (Soluble organic Fractions) + O₂ (Oxygen) → CO₂ (Carbon Dioxide) H₂O (Water)

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Diesel Particulate Filter (DPF)



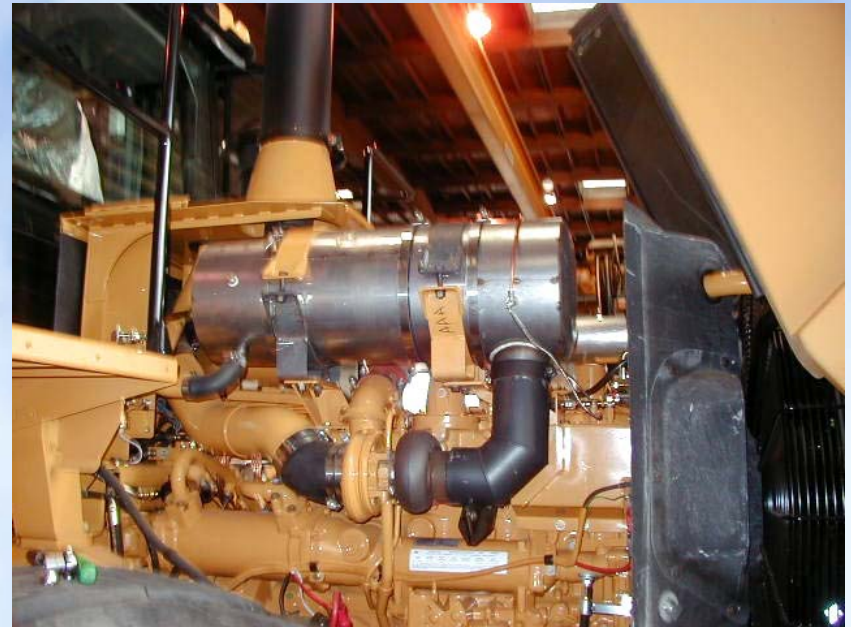
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Diesel Particulate Filter

- Porous filter material that allow exhaust flow while collecting particulate
- Advantages
 - High particulate reduction
- Disadvantages
 - Expensive
 - Requires ultra low Sulfur fuel
 - Regeneration requirements

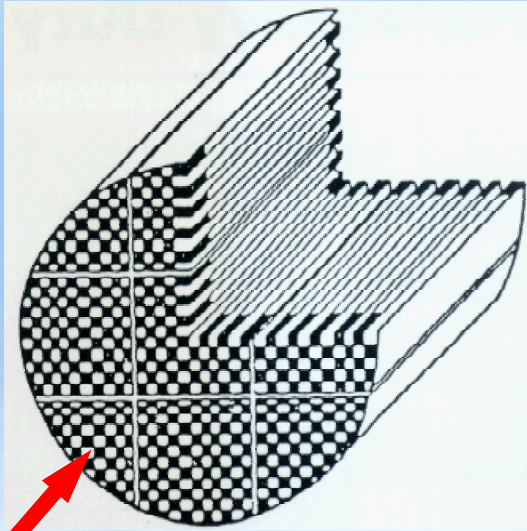
Diesel Particulate Filters

- Emissions Targeted
 - HC, CO, and PM
- Application dependant
 - Exhaust temperature/duty cycle
- Size, location, durability
- Recommended on Tier 1 or newer off road engines.
- Requires ultra low sulfur diesel fuel (ULSD)

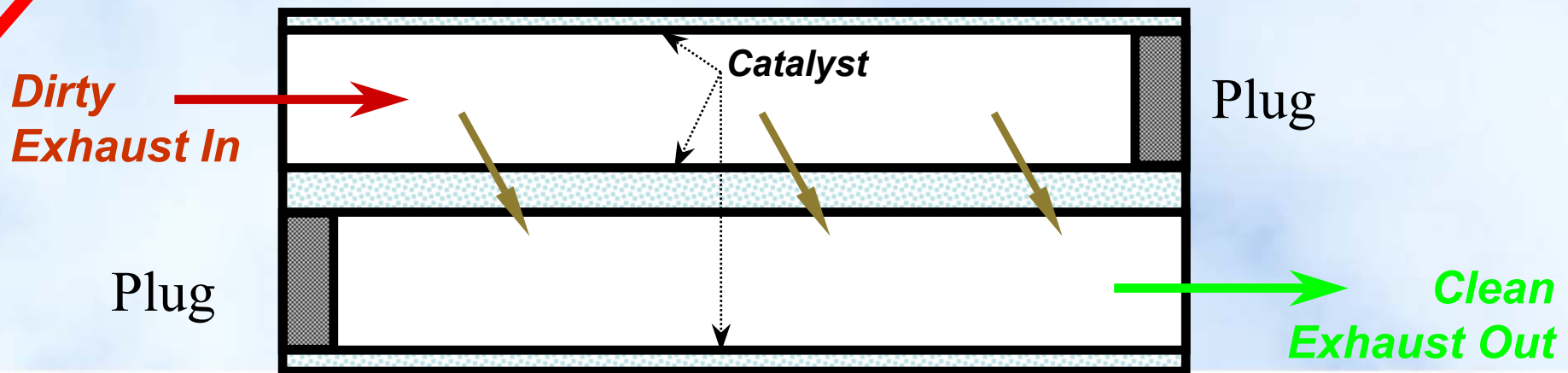


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Passive Particulate Filter

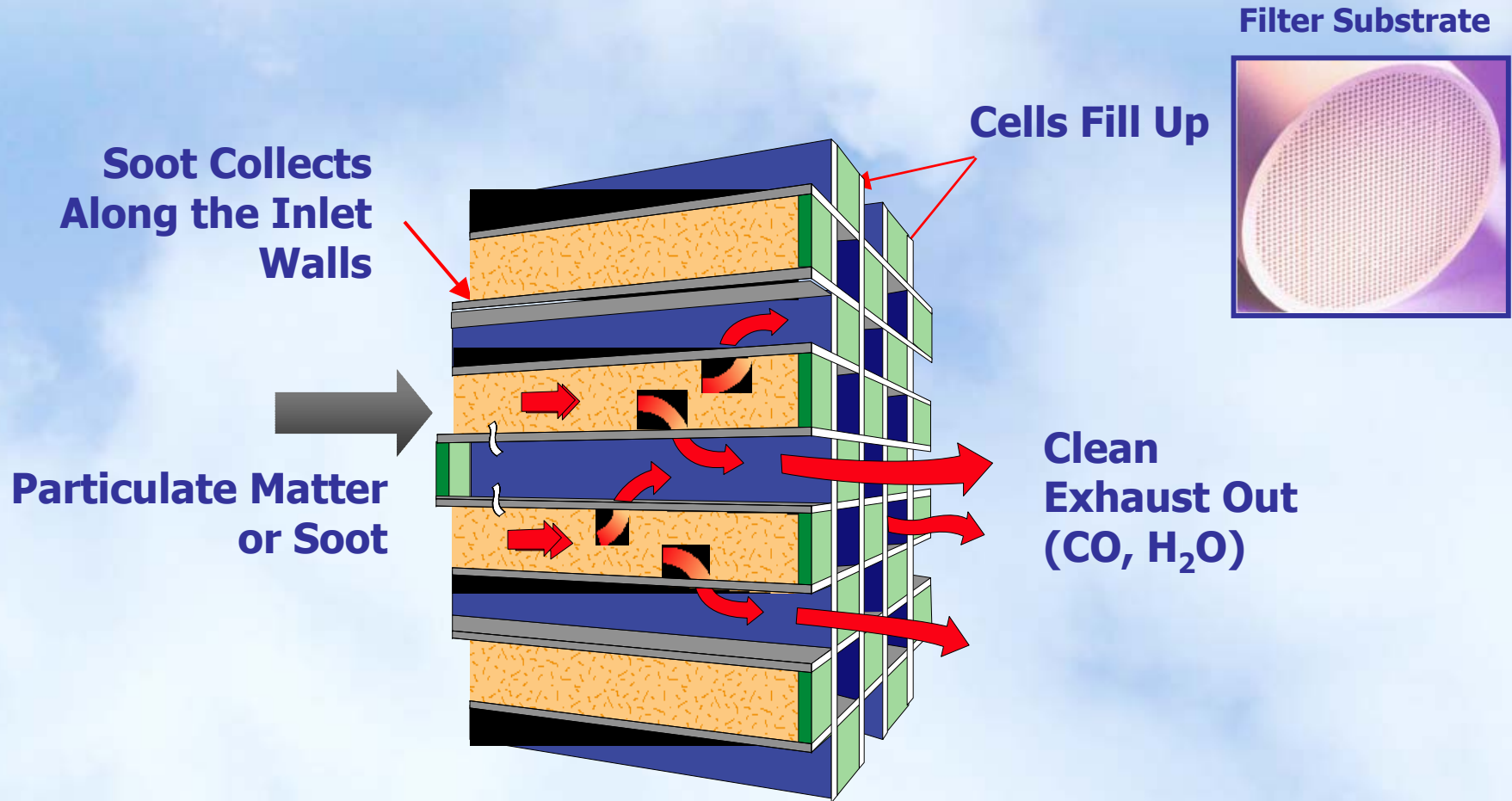


- Ceramic Honeycomb Structure with Alternate Plugged Channels. Catalyst Applied to Filter Channel Walls
- Exhaust Enters Inlet Filter Channel - Forced to Flow Through Porous Ceramic Wall
- Soot Particles are Filtered from Exhaust at Inlet Channel Wall (Surface Filtration)
- Accumulating Soot Layer is “Burned Off” to Prevent Increased Backpressure



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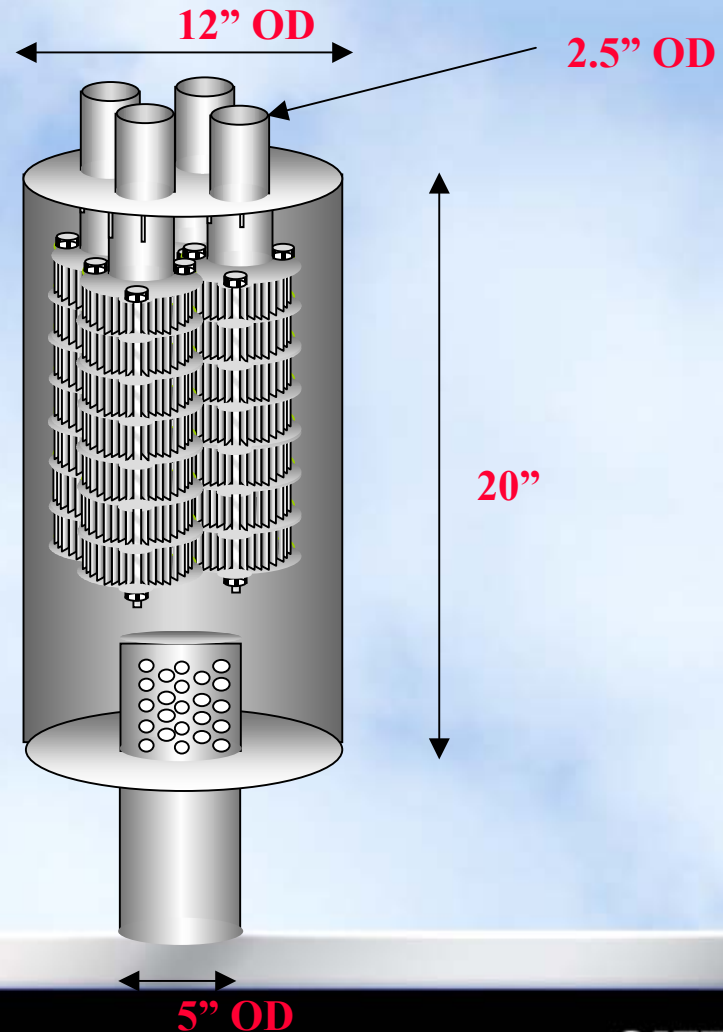
Wall Flow Filter Technology



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Active Particulate Filter

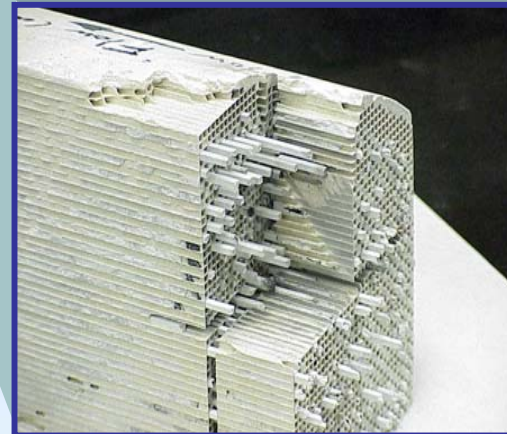
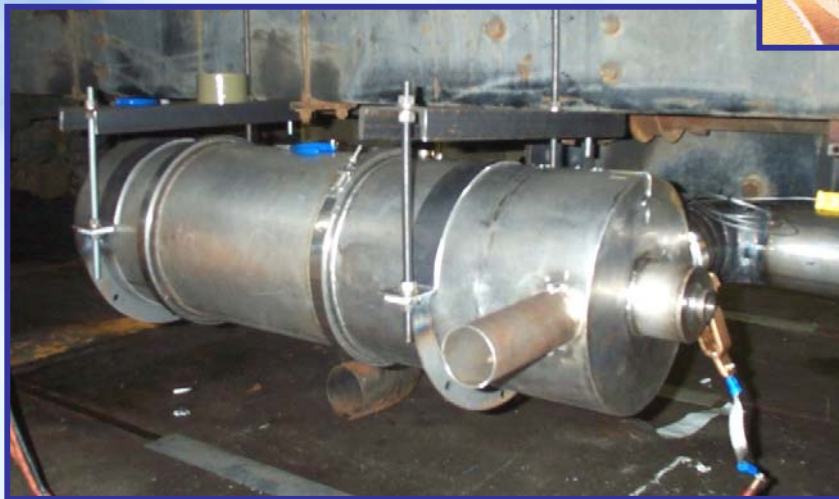
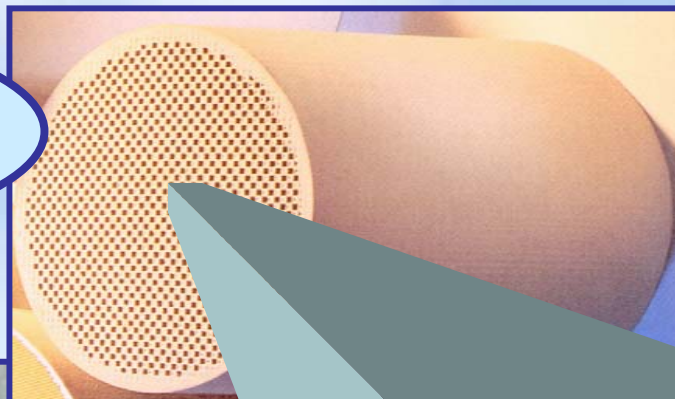
- Metallic fiber traps particulate
- Electric current programmed for periodic regeneration
- Also fuel fired regeneration



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DPF Cleaning

Ash needs to be removed
in a regular maintenance
schedule



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DPF Cleaning

- **Intervals**

- Minimum Interval is 150,000 Miles
- Caterpillar's ACERT target is twice this high.
 - ✓ Idle time / Load Factor

- **Method**

- On Vehicle or Off Vehicle
 - ✓ On vehicle saves time and expense

- **Cost**

- Targeted Service Cost is 2 hours of shop labor
 - ✓ Disposal Cost?

Selective Catalytic Reduction (SCR)

- Emissions targeted
 - Nitrogen Oxides (NOx)
- Effective & proven for stationary applications
- Size to application
 - Exhaust mass flow
- Not fuel dependent
- Not a prime candidate for mobile applications

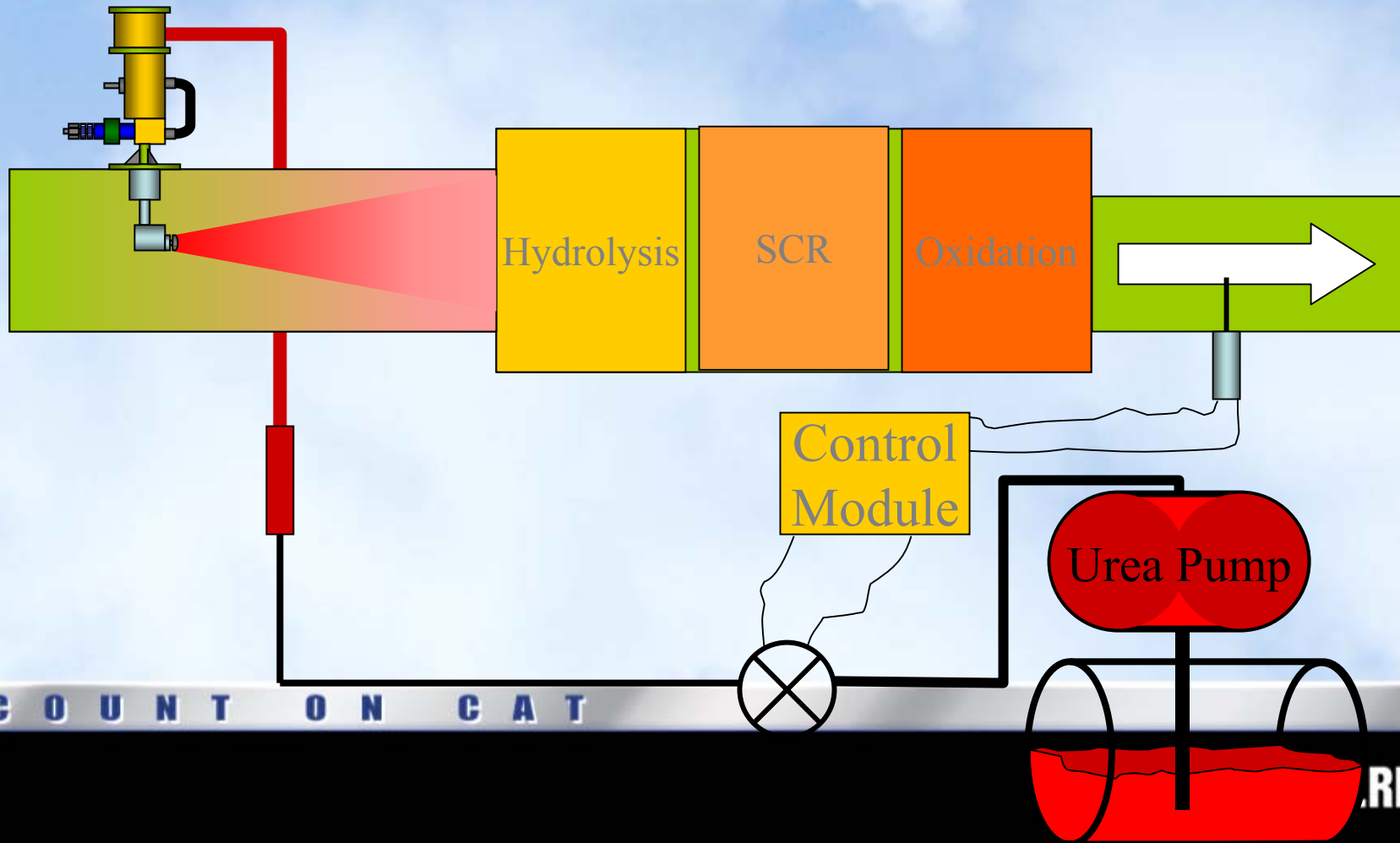


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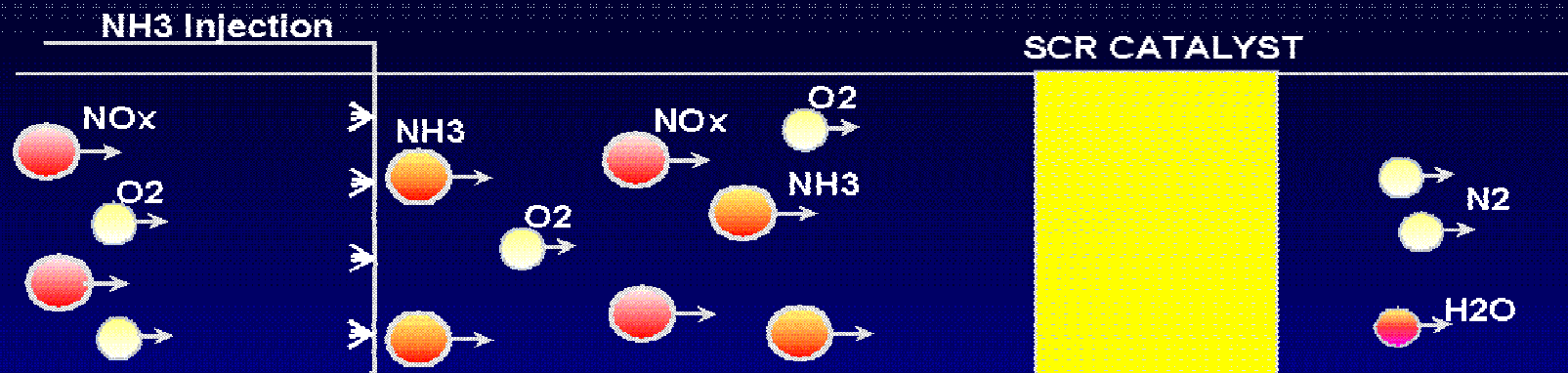
Urea SCR

- Urea - $\text{CO}(\text{NH}_2)_2$ reagent is injected into the exhaust stream in front of an SCR catalyst to selectively reduce NO_x to N_2 and H_2O
- NO_x reductions of 70% to 90% at typical exhaust temperatures of 320°C to 450°C
- Cost effectiveness @ < \$1,500/ton NO_x
- Approximately 2 tons of 32.5% urea solution per ton NO_x removed
- Not a prime candidate for mobile applications

Aftertreatment- Catalysts



Selective Catalytic Reduction



Primary Reactions:

- $4\text{NO} + 4\text{NH}_3 + \text{O}_2 = 4\text{N}_2 + 6\text{H}_2\text{O}$
- $6\text{NO}_2 + 8\text{NH}_3 = 7\text{N}_2 + 12\text{H}_2\text{O}$
- $\text{NO} + \text{NO}_2 + 2\text{NH}_3 = 2\text{N}_2 + 3\text{H}_2\text{O}$

Fuel, Oil & Additive Technology

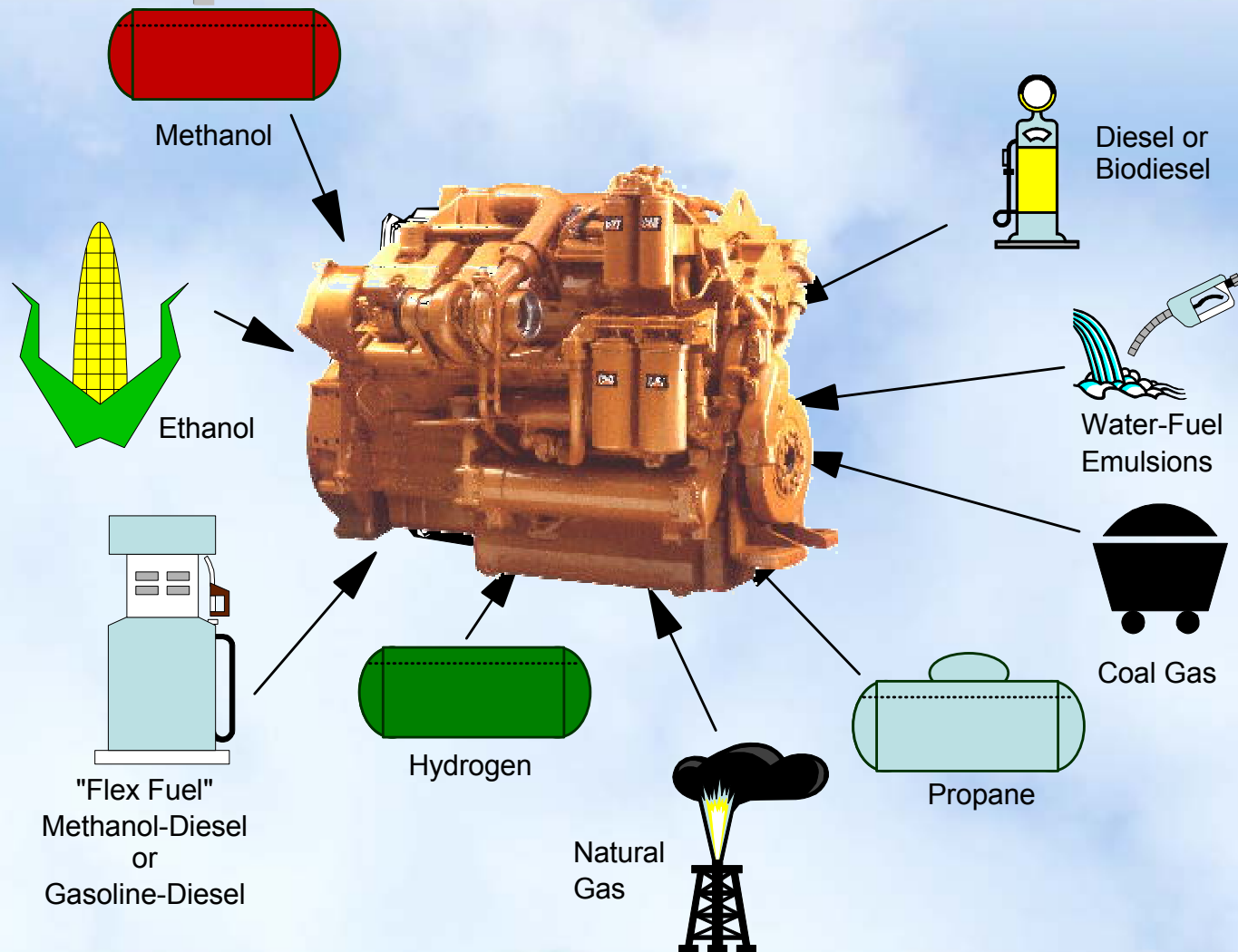
- Fuel & lube oil
- Alternative diesel fuels
- Fuel additives

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Fuels

- **Ultra Low Sulfur Diesel (<15 ppm sulfur)**
- **Biodiesel**
 - Up to B100 for engines > 150 HP
 - Up to B5 for engines < 150 HP
 - Must meet Caterpillar's biodiesel specification, ASTM PS121, or DIN 51606
- **Water Emulsified Fuels**
 - Lubrizol's PuriNOx fuel can be used in the following engines: 3208, 3304, 3306, 3406B&C, 3408B&C, 3412B&C
 - Additional engines are being tested

Development - Alternative Fuels



C O U N T O N C A T

➤ Utilize diesel cycle with range of fuels.

CATERPILLAR®

Focus On Fuel



- Co-develop low emission diesel fuel
- Complementary fit between leaders in diesel engine and chemical technologies
- New low emission diesel fuel/water blends & blending technology called - PuriNOx
- No modifications to fuel systems or engine hardware required
- Estimated reductions of NOx by 5 to 30% & PM by 20 to 50%
- Currently being tested in a variety of Cat engines and different machine applications

C O U N T O N C

Emissions Repower Program

- New and Reman arrangements available
 - 90 different machine models covered
- Engine performance to match machine requirements
- Extended warranty
 - Includes parts and labor when installed by a Caterpillar Dealer
- Caterpillar Certified Rebuild Program



C O U N T O N C A T

**There are no easy answers,
just intelligent choices**

Questions?

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